Advanced Glass Reinforcement Technology for Improved Signal Integrity

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Abstract

An innovative approach to glass fiber reinforcement in laminates promises to resolve existing challenges with mechanical, electrical, and performance characteristics typically encountered in today's high tech printed circuit designs.

This uniquely woven glass fabric is flatter and thinner, which results in a more uniform laminate for mechanical and laser drilling. Furthermore, special properties of the glass fibers and the glass-to-resin interface predict improved CAF resistance.

Performance characteristics are greatly enhanced due to homogeneous insulating layers between copper traces. A diminished "fiber weave effect" (FWE) is proposed as a function of homogeneity. Corollary signal skew is completely eliminated as a performance consideration.

In its leading edge form, a proprietary glass reinforcement is combined with a high performance resin system to produce a laminate which provides superior signal integrity. Initial test results indicate a high performance system (FR-4 processable) with electrical characteristics of Dk = 3.00 and Df = 0.0040 at 10GHz.

Introduction

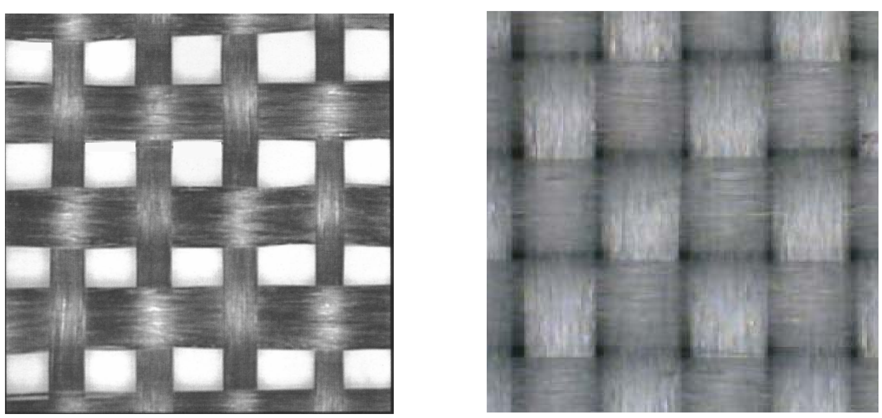
Among the many challenges facing the electronics industry today are those related to the "need for speed". These include improved signal integrity requirements and increased product reliability, while at multi-GHz clock rates smaller threshold voltages and faster rise/fall times in picoseconds continue to challenge the industry to provide novel solutions. Numerous technical papers in recent years have proposed methods to deal with these challenges coining the phrase "fiber weave effect" or FWE to express one of the central issues. [1-7] While many solutions have been presented to deal with FWE, none have addressed the actual fiber in question, the woven glass fabric in the laminate material. The questions posed are this: Can an innovative glass fabric technology improve end product performance? Can a raw material so far back in the supply chain have an impact on leading edge industry challenges?

The answer is Yes. Dielectric Solutions has developed a proprietary high performance glass fabric technology that demonstrates uniformity of glass weave resulting in a homogeneous reinforcement layer. In concert with readily available resin technologies, it can provide improved physical properties (laser and mechanical drilling, dimensional stability and surface smoothness), superior electrical properties (CAF resistance), and enhanced performance properties (more uniform Dk and circuit impedance, reduced signal skew, and improved signal integrity).[8]

Discussion

Many solutions have been proposed to address FWE in a circuit board.[6,7] However, through all of them there has been an implicit assumption that the glass fabric reinforcement layer itself cannot be improved upon; this is not true. Consider a Style 1080 fabric, perhaps the most commonly used glass fabric in high performance multilayer PCBs. The standard construction of this style involves 60 yarns per inch in the warp or machine direction and 47 yarns per inch in the weft or cross-machine direction. The 1080 designation also specifies the type of yarn, as per IPC-4412A.[9]

Figure 1 shows two 1080 fabrics that have obvious physical differences, though both have been made according to the IPC specification.[9] On the left is a traditional 1080 fabric while on the right is the high performance glass fabric aforementioned. Each has exactly the same quantity of glass with the same number of warp and weft yarns. The most obvious physical difference between these fabrics is the spread out ribbon-like yarns in the right-hand photo. To determine the properties of these fabrics, we must first understand the underlying technologies.



a) Standard b) Advanced

Figure 1: Standard versus the advanced glass fabric in 1080 style.

DirectFinish™ processing –In the manufacture of traditional fiber glass, the yarns are coated with a vegetable-based starch-oil mixture to facilitate weaving. This coating is then removed in a lengthy heat clean step after which the yarn bundle receives a silane coating. Depending on the tightness of the weave and/or any ash residue left from the heat cleaning, the individual yarns may or may not be fully wetted by the resin matrix. In addition, the heat cleaning step reduces the glass fabric strength by approximately one third. Therefore, elimination of this damaging step will create a stronger, more dimensionally stable composite.

Direct application of a final resin-compatible finish during the fiber-forming process provides a better interface between the glass fiber reinforcement and the resin matrix.[8] This resin-compatible finish is applied to the pristine surface of individual glass fibers immediately *as they are formed*, and remains on the yarn and glass cloth throughout the manufacturing process.

TwistFree™ Yarn – Figure 2 illustrates the differences between a twisted fiber bundle and the advanced untwisted yarn. Traditionally, the glass fiber bundle is twisted to give strength and mechanical integrity to the yarn and make it easier to weave into fabric. Twisted yarns are somewhat rope-like, making thicker cross-points in the glass fabric (often referred to as knuckles). Twisted glass fiber is also a known contributor to stresses within the laminate.

An untwisted yarn is more ribbon-like, lies flat and spreads out easily. TwistFree™ yarn construction yields a more consistent, more uniform fabric, where glass fibers are more uniformly distributed, and weave knuckles and open areas are minimized.

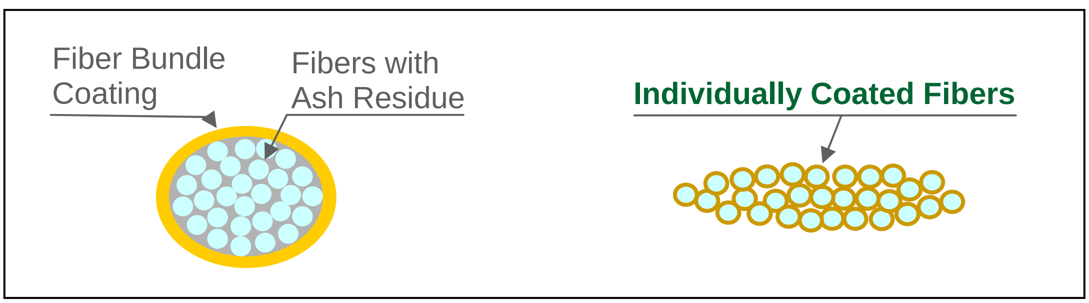


Figure 2: Traditional Yarn vs. TwistFree™, DirectFinish™ Yarn

Refer again to Figure 1, which shows two different fabrics with the same amount of glass, but with the glass fibers distributed differently. The traditional glass reinforcement (1a) is thicker and unevenly distributed, leading to inconsistent substrate properties. There are essentially three differing glass thicknesses in the fabric: areas with two layers of yarns (at the knuckles); areas with just one layer; and the interstices between the yarns where there is no glass. In Figure 1a these areas are very distinct from each other, while in Figure 1b the fibers have been spread out to fill the interstices.

Figure 3 further illustrates this concept. For the best mechanical, electrical and performance properties, total glass uniformity is key. This is a direct result of maximizing the amount of 2-layer coverage. In Figure 3 we have quantified the amount of 0-, 1-, and 2-layer coverage using red, yellow and green areas (respectively) over-layed on the photos from Figure 1. The percentages shown are based on measurements from the photographic images.

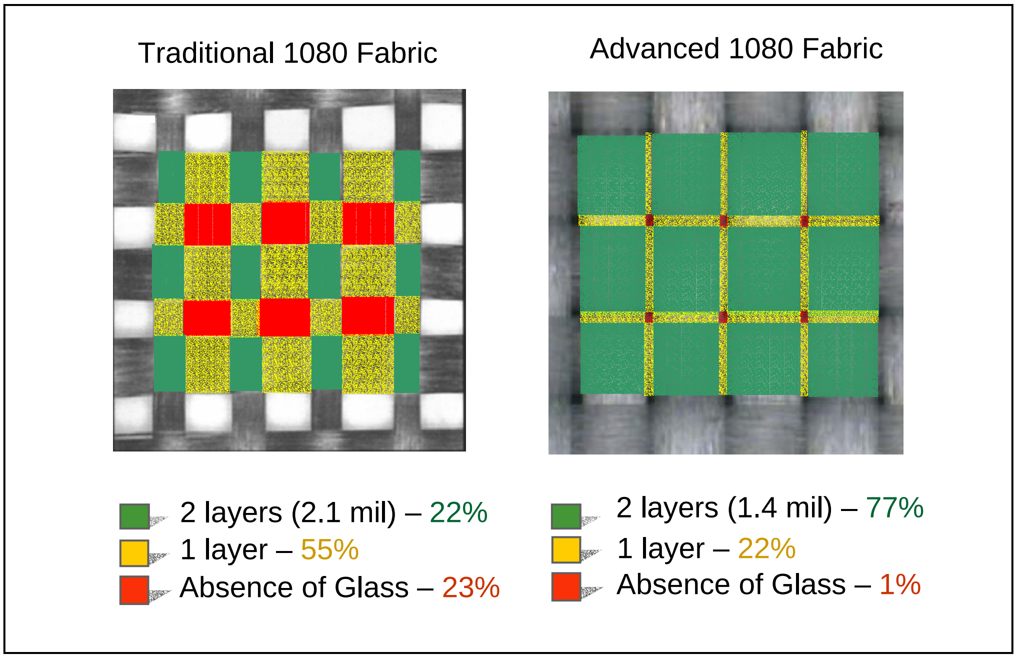


Figure 3: Colors over-layed on the photos to illustrate layer coverage

Considering that these two fabrics contain the same amount of glass, it can be presumed that the fabric in Figure 1b is thinner than 1a, and this is indeed the case as confirmed by measuring total fabric thickness.[9] In fact, the two-layer areas of glass in the traditional fabric are ~50% thicker than the two-layer areas in the advanced glass on the right (2.1 mils vs. 1.4 mils).

Low Dk Glass – In addition to a more uniform glass configuration, the NovaSpeed™ utilizes a lower dielectric constant (Dk) glass composition to reduce the Dk difference between glass and resin. This Dk difference is the root cause of FWE. In traditional 1080 fabric using E-glass, the Dk difference between the glass and high performance resin is approximately 4 units. With NovaSpeed™ fabric the Dk difference is reduced by half. Then the more uniform fiber configuration is applied.

In Figure 4 the photos from Figure 1 have been over-layed with 3-mil lines to approximate scale for illustration purposes. Both fabrics have the same amount of glass but distributed differently. Estimates of single end impedance and effective Dk variation for traditional 1080 fabric are based on data presented in a paper by Brist et al at IPC Expo 2004.[2]

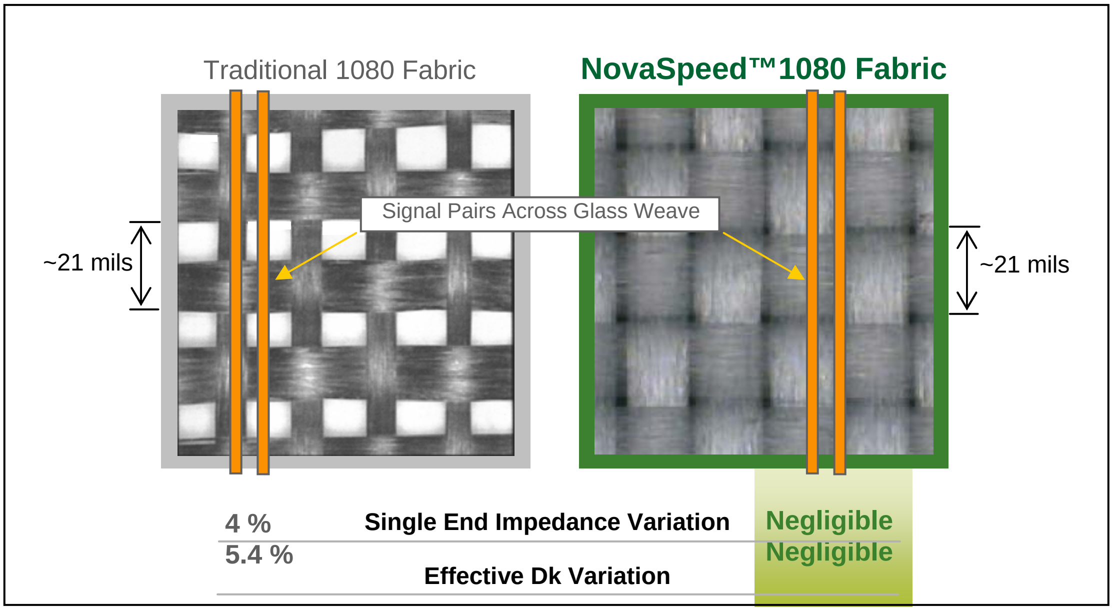


Figure 4: Improved signal integrity and clock rate.

As stated at the beginning of this discussion, many solutions have been proposed to address FWE in printed circuitry. Among these solutions is the use of a heavier fabric style that has a balanced construction and tighter weave, which reduces the open spaces.[7] However, addressing the issue by glass style alone does not improve upon the other important aspects discussed above. Indeed, laminate core thickness below about 4.0 mils cannot be achieved using these heavier fabric styles.

Test Results

Table I shows initial test data on glass fabrics. The thickness measurements are per ASTM D579 (25 psi). Dielectric constant (Dk) and dissipation factor (Df) for NovaSpeed™ 1080 were measured at 10 GHz using the NIST split cavity method at the Materials Research Lab at Pennsylvania State University.[10] These measurements were subsequently corroborated by calculations from test laminates per IPC-TM-2.5.5.5 (stripline method). The traditional 1080 Dk and Df measurements were taken from a table compiled by IPC 3-12d Glass Reinforcement Task Group and represent data from four global manufacturers of E-glass yarn.[11]

As previously described, the Dk of the NovaSpeed glass fabric is lower than that of E-glass in traditional fabric. More precisely, the Dk of this fabric is halfway between that of E-glass and typical high performance resin systems. Thus the Dk difference between glass and resin is half of that seen in the current state-of-the-art.

Table I

	Traditional 1080	NovaSpeed™ 1080
Fabric Thickness	2.1 mil (mm)	1.4 mil (mm)
% Coverage (2 / 1 / 0 layers)	22 / 55 / 23	77 / 22 / 1
Dielectric Constant (Dk)	6.6 – 6.9	4.5 – 5.0
Dissipation Factor (Df)	0.006 (avg.)	0.005 (avg.)

Table II shows Dk and Df results with the NovaSpeed™ 1080 glass fabric alone and in three commercially available resin systems. The resin systems, while high performance, are not characterized as "exotic" but are considered to be "FR-4 processable". The bulk glass measurements were done using the NIST split cavity method and all other measurements are per IPC-TM-650 2.5.5.5 stripline method.

Table II

Material	Dk	Df
Glass Reinforcement	4.5 to 5.0	.005
Laminate A	2.97	.0079
Laminate B	3.12	.0080
Laminate C	2.98	.0039

Conclusions and Summary

Based on the known characteristics of the advanced glass fabric, a number of direct improvements can be predicted. The flat, smooth glass fabric is akin to a laser-drillable fabric with improved laminate surface planarity and inherently lower surface roughness, as compared to laminate made with traditional glass fabrics. Improvements in "telegraphing", laser-drilled hole geometry, hole plating quality and laser drilling speed can be expected. A reduction in mechanical drill wander is also expected. Furthermore, the high strength properties of DirectFinish™ fabric, combined with the more uniform distribution of the glass fiber yarns, provides improved dimensional stability in laminate for circuit board applications.

The use of DirectFinish™ technology combined with the spread fibers of TwistFree™ yarn results in greatly improved wettability and resin impregnation (of the glass bundles); therefore the highest quality glass-to-resin bond is ensured. This property is the main factor in improved CAF resistance. An electrochemical migration phenomenon similar to CAF is caused by hollow fibers. The low Dk glass formulation used in NovaSpeed™ fabric exhibits zero hollow fibers. Table III summarizes these characteristics and corresponding quality and reliability improvements.

Table III

Characteristics	Quality/Reliability Improvements
o Flat, Smooth, Thin Glass Weave	o Laser Drilling – time/cost savings, hole quality
o DirectFinish™ Technology	o Mechanical Drilling
o Homogeneous Spread Fiber Weave	o CAF Resistance
o No Hollow Fibers	o Higher Production Yield

Table IV identifies performance improvements of NovaSpeed™ fabric resulting from the combination of DirectFinish™ and TwistFree™ technologies, and using a proprietary low Dk glass formulation. The printed circuit substrate exhibits a homogeneous Dk and Df leading directly to less impedance variation and reduced signal skew. These result in improved signal integrity.

Table IV

Characteristics	Performance Improvements
o Flat, Smooth, Thin Glass Weave	o Homogeneous Dk/Df
o Low Dk/Df	o Less Impedance Variation
o Homogeneous Spread Fiber Configuration	o Much Reduced Signal Skew
	o Improved Signal Integrity

An advanced reinforcement material has been utilized to generate 10 GHz test data in several high performance commercial resin systems. These high performance laminates have demonstrated superior electrical properties. Prior metrics for substrate material performance focused on bulk Dk and Df with the implication that the reinforcement was untouchable. However, using a unique manufacturing process, the reinforcing glass fibers are uniformly distributed in both directions. This provides a homogeneous reinforcement layer unlike traditional glass fabrics. In fact, the key features of NovaSpeed technology are not addressed by existing industry specifications.

It is our expectation that "fiber weave effect" or FWE can be completely eliminated as a performance constraint in PCB substrates. For these reasons NovaSpeed™ technology represents a paradigm shift for PCB substrate performance.

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